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Approved for public release; distribution unlimited (PA #11553).

13. SUPPLEMENTARY NOTES

For presentation at the AIAA Modeling and Simulation Conference, Portland, OR, 8-11 August 2011.

14. ABSTRACT

Modeling and simulation is a key enabler for the systems engineering process and can support the affordability goals for new programs by performing trade studies during the pre-acquisition phase of new programs. Modeling and simulation allows program managers and designers to assess the impact of system requirements and the introduction of new technologies early in the design phase and to assess alternative concepts, identifying the best approach to fulfill the requirements before significant funding has been expended. Advatech Pacific, Inc. (Advatech), is under the direction of the Air Force Research Laboratory (AFRL), and with their support is currently developing the Integrated System and Cost Modeling (ISCM) tool suite that addresses the impact of system requirements and technology insertion and explores trade spaces throughout the life cycle of a program.

15. SUBJECT TERMS

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An Integrated Approach to Systems Engineering through Modeling and Simulation

Presenter:

Michael O'Such

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Advatech Pacific, Inc. Background

An Aerospace Engineering Research & Development Company Founded in 1995 primarily focused on:

- Aerospace Vehicle Physics-based Modeling, Simulation and Analysis
- Electronic Communications System Interoperability
- Aerospace Engineering Design and Analysis Services

Past M&S Efforts

- IPAT (Effort Began: 2002)
  - Expansion of Reusable Military Launch System (RMLS) developed at WPAFB
  - Developed for rapid assessment of launch vehicle designs for AFRL/RZST
  - Integration of industry standard tools (CEA, POST, MINIVER, DATCOM)
  - Various propulsion types and vehicle types modeled
- ACES-ISET (Effort Began: 2003)
  - Developed to fulfill the need for an overall space mission trade study tool for AFRL/RV
  - Integrates the Space Mission and Analysis Design worksheet for spacecraft assessment and additional mass-estimating relationships for small satellites
  - Models spacecraft radiation environment
  - Unmanned Space Vehicle Cost Model, Small Satellite Cost Model, NASA Instrument Cost Model used to estimate spacecraft costs
  - Integrates launch vehicles from a database of existing launch vehicle or can import a launch vehicle model from IPAT

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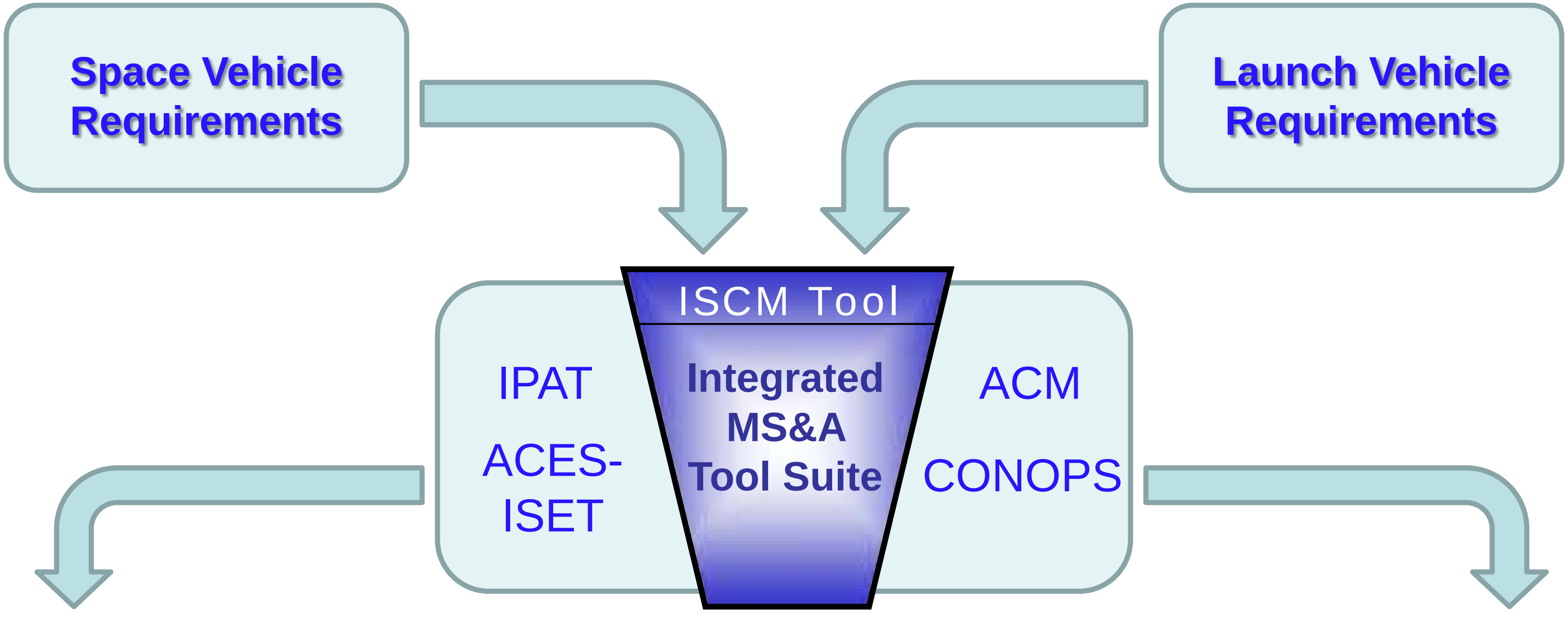
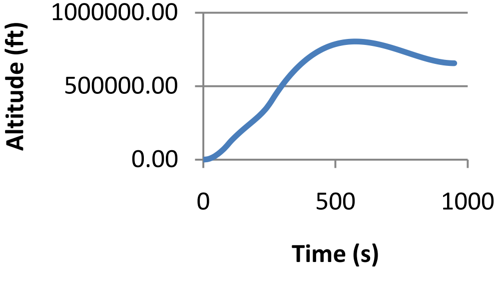
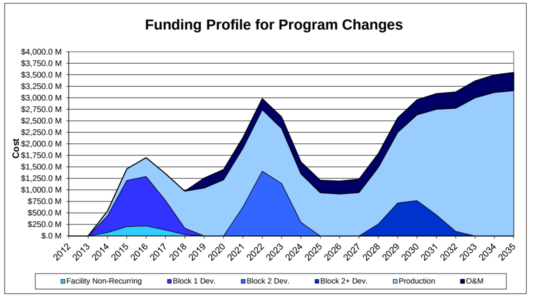
Past M&S Efforts

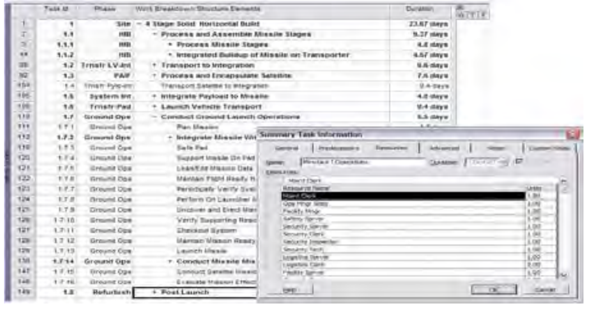
- ACM (Effort Began: 2006)
  - Uses CERs and acquisition strategies to estimate development, procurement and top-level launch costs for expendable and solid launch vehicles
  - CERs developed by Dr. Roy Smoker of MCR using historical program data, statistical analysis, and NASA and DoD TRLs
  - Incorporates risk assessment
  - Integrated with IPAT
- CONOPS (Effort Began: 2009)
  - Analysis of faculties and labor cost
  - Launch availability and reliability estimates
  - Generates baseline launch operations schedule
  - Integrated with IPAT and ACES-ISET

ISCM Integration Concept

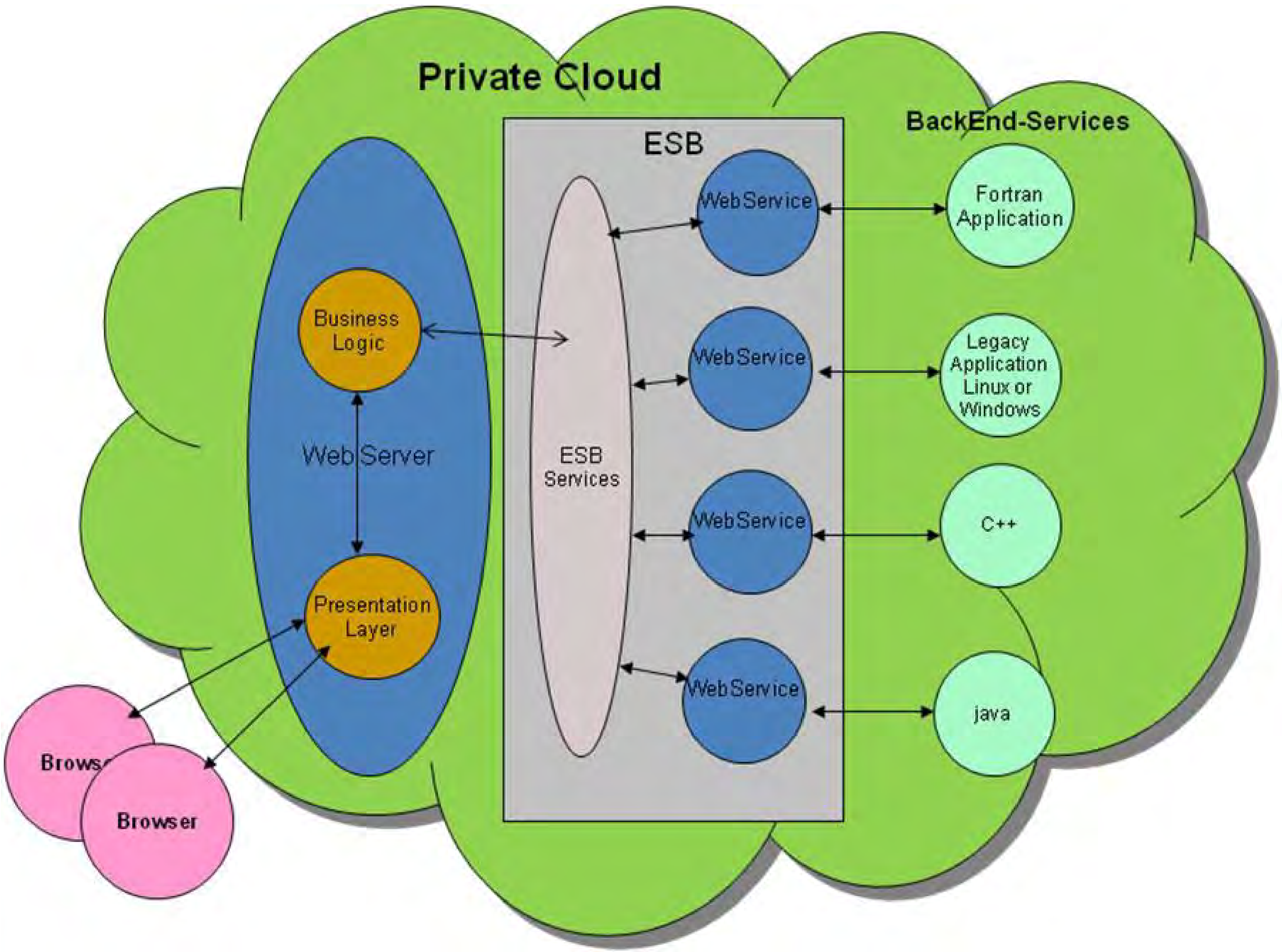








ISCM Service-Oriented Architecture



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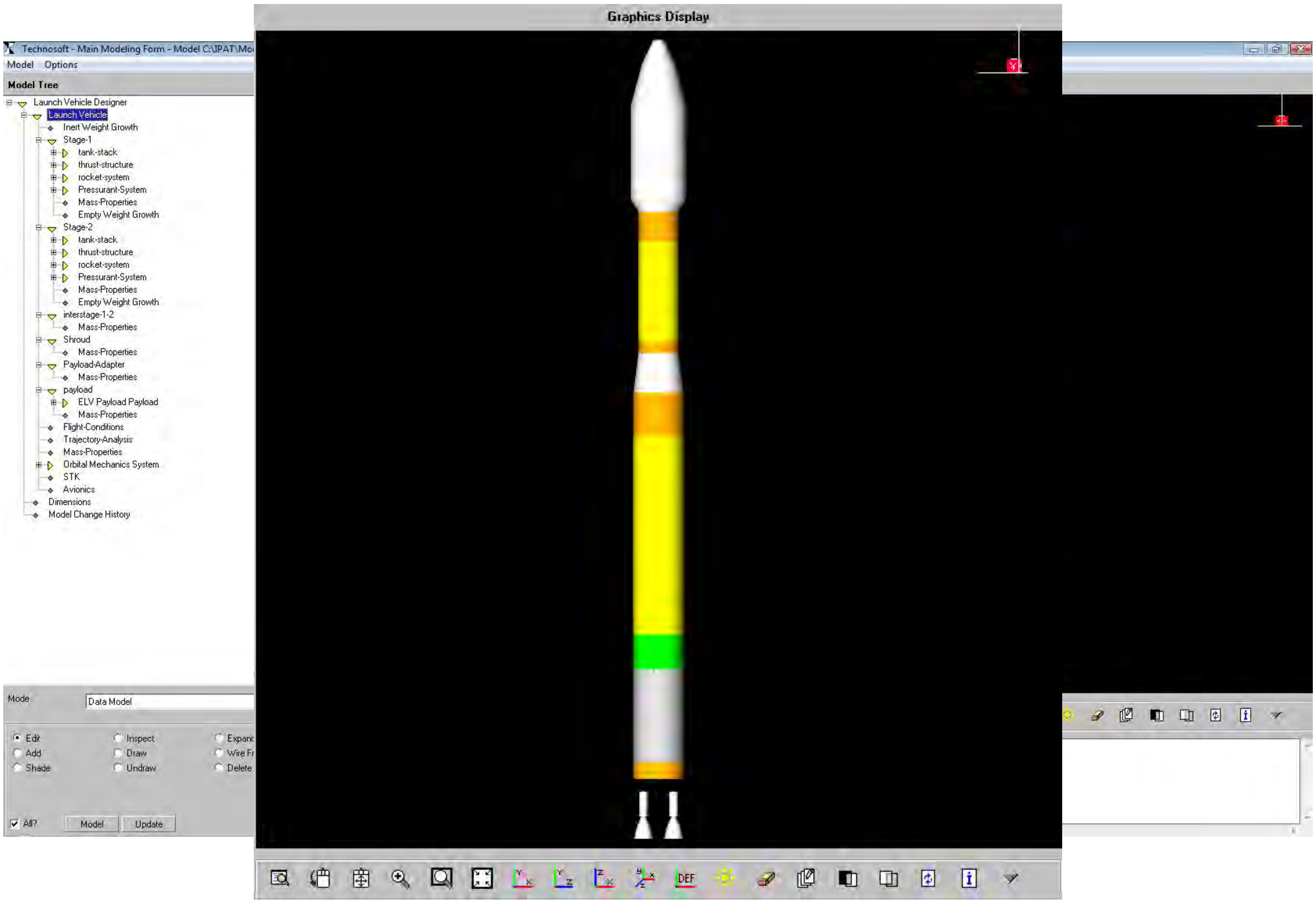
Launch Vehicle Performance



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Space Vehicles

Prelim. Sizing

Orbits
- Dynamics
- Geometry
- Maneuvers
- Patched Conic
- Budgets

Payload
- Subject – EM Spectrum
- Obs Payload - Optics
- Obs Payload - Sizing
- Secondary Payloads

SC Bus – Preliminary Sizing

Higher Fidelity S/C Sizing

SC Bus – Preliminary Sizing

Attitude Control
- Torques
- Sizing

Communications
- Uplink
- Downlink

Power Sub-Systems
- Solar Arrays
- Secondary Batteries
- Other Primary Sources

Propulsion
- Sizing
- Thermodynamics
- Storage & Feed

Structure
- Monocoque
- Semi-Monocoque

Thermal
- Spherical
- Solar Array

System Sizing Summary

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Launch Vehicle Cost Analysis

- Parametric Estimation: $AUC_i = \alpha_i W_i^{\beta i}$
- Historical data derives cost-estimating relationships (α and β values)
- CERs tied to TRLs and project milestones (PDR, CDR, etc)
- Complete life-cycle costs with risk analysis (FRISK) incorporated

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Launch Vehicle Cost Analysis

TRL	NASA	Defense Acquisition Management Framework
1	Basic principles observed and reported	Paper studies of alternative concepts for meeting a mission
2	Technology concept and/or application formulated	Analysis of alternatives; Validated and approved needs Statement (MNS); Exit criteria: Having specific concept to be pursued and technology exists
3	Analytical and experimental critical function and/or characteristic proof of concept	Concept in hand, but system architecture to be developed; Exit criteria: Development Contract Awarded
4	Component and/or breadboard validation in laboratory environment	Architecture complete, but components need to be integrated into complete system; Exit criteria: Preliminary Design Review (PDR)
5	Component and/or breadboard validation in relevant environment	System prototypes demonstrated in relevant environment; Exit criteria: Critical Design Review (CDR)
6	System/subsystem model or prototype demonstration in a relevant environment	System demonstrated in its intended environment; Exit criteria: System Verification Review (SVR)
7	System prototype demonstration in a space (if applicable) environment	Technically Mature; Low Rate Initial Production; Exit Criteria: Initial Operational Capability (IOC)
8	Actual system demonstration and "flight qualified"	Initial Operational Capability; System operationally effective; Exit Criteria: Manufacturing ready for full-rate production
9	Actual system "flight-proven" through successful mission operation	Full-rate production; Deploy System; Exit Criteria: Full Operational Capability

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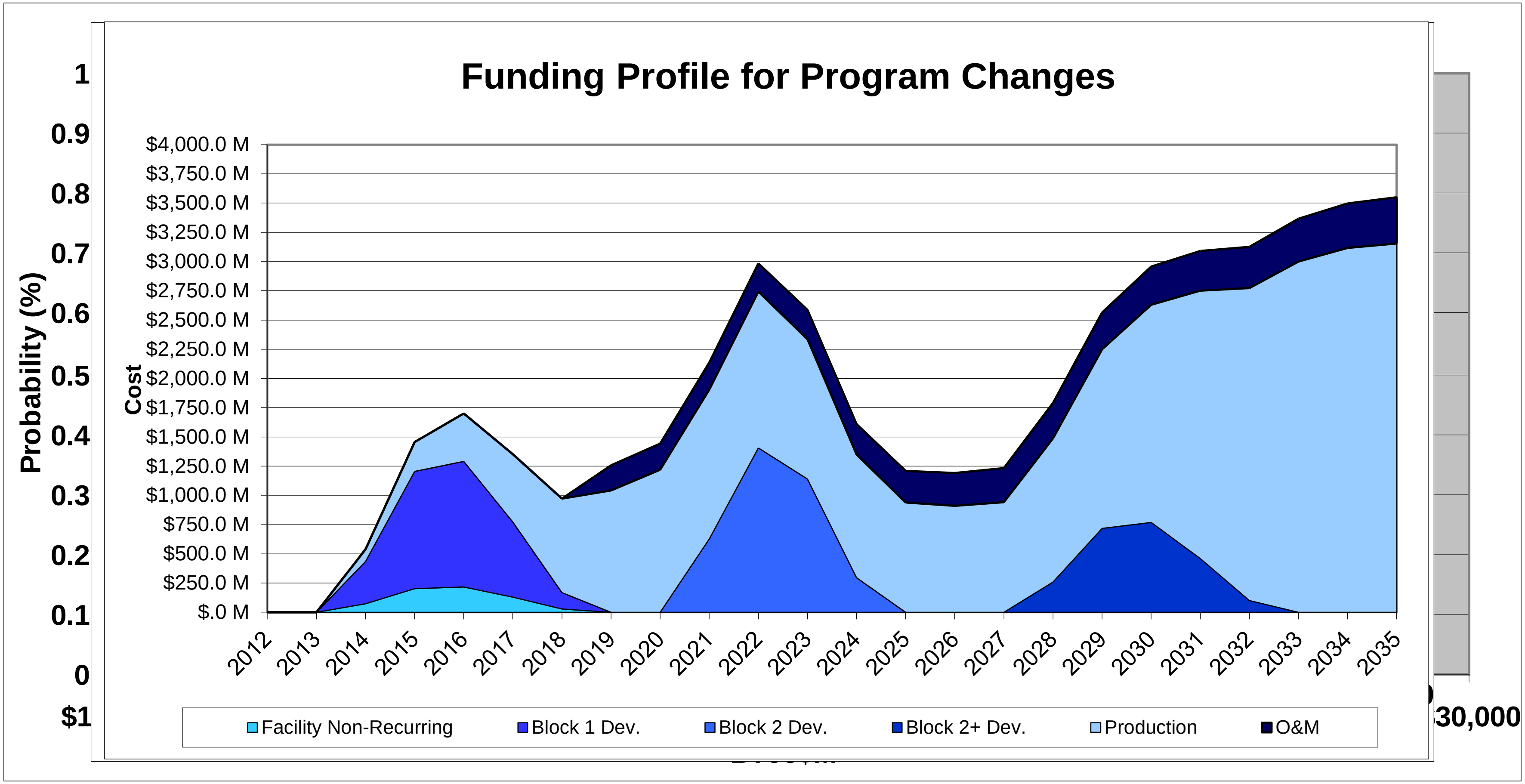
Launch Vehicle Cost Analysis



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Space Vehicle Cost Analysis

- Excel-based model includes several validated cost models
  - Unmanned Space Vehicle Cost Model (USCM)
  - Small Satellite Cost Model (SSCM)
  - NASA Instrument Cost Model (NICM)
  - Constructive Cost Model II (COCOMO II)
- Air Force Cost Analysis Agency (AFCAA) Schedule Estimating Relationships
- FRISK used to apply risk to life-cycle costs

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Space Vehicle Cost Analysis

- Cost model outputs:
  - RDT&E
  - First unit cost
  - Additional unit cost
  - Total cost
- Heritage factors applied to RDT&E
- Bus and payload information used to generate total RDT&E
- Generated cost used to determine IA&T, PL and GSE cost
- Outputs broken down by WBS

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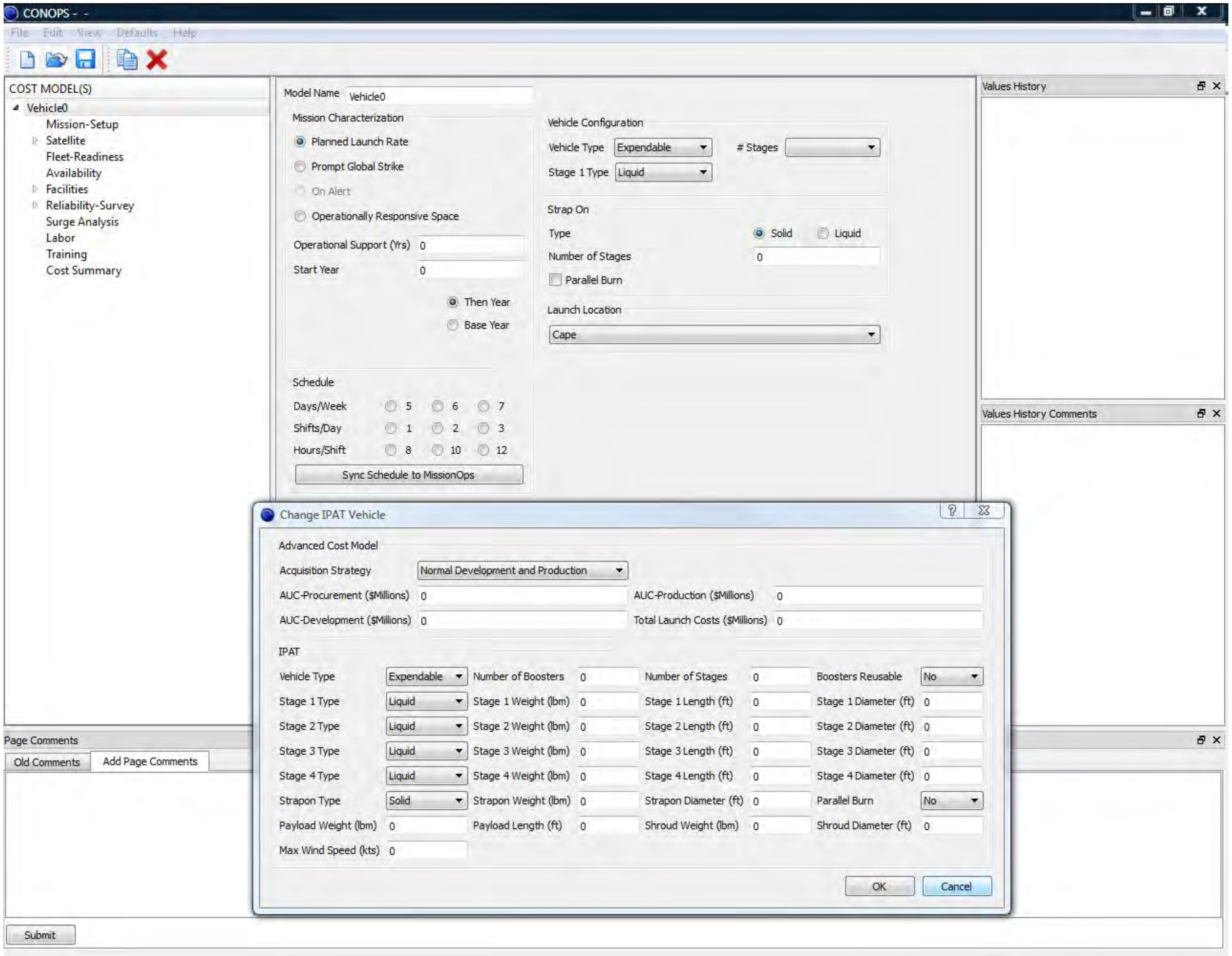
Operations and Maintenance



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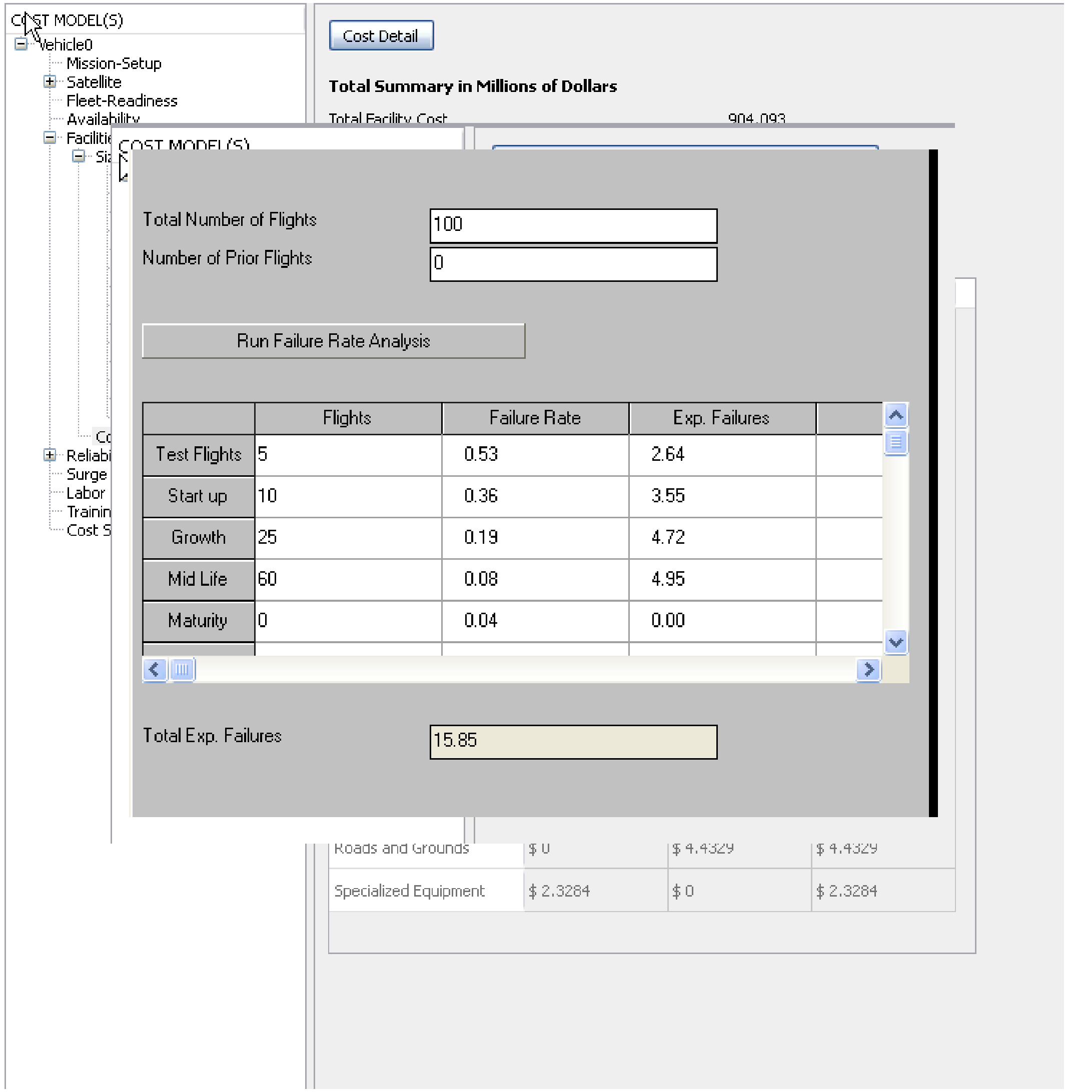
Operations and Maintenance



Previous Studies

"Operational" TacSat-3 Procurement Costs Relative to Changes in Design

Results produced in a few hours after design found to deviate from requirements - Identified impacts of changes

Facility Set-up and Sustainment for Rapid Response Space Works

Comprehensive Life Cycle Cost Analysis completed in two months -

Integrated Project Team

ISCM Tool

- Cost
- Risk
- CONOPS
- Schedule
- Operability
- Performance

Knowledge Database Buildup

Fully Reusable Two Stage To Orbit Vehicle Optimized

68% Reduction in Orbital Weight

40% Reduction in Gross Vehicle Weight – What if study looking at TSTO options

Small Launch Vehicle Study

Small Launch Vehicle Study of Falcon 1 Vehicle

Predicted 3.5 Failures Out of First 5 Flights (Note: Current Falcon 1 Failures are at 3 of 4 launches)

Previous Studies (cont'd)

Four Launch Vehicles Modeled In ISCM

Delta II, Atlas V, Minotaur I, Falcon 1

Modeled weights within 2% of published values

TacSat -5 Concept Evaluations

Thirteen Concepts for TacSat – 5 Evaluated Using Tool Suite

Identified requirements not met and inaccurate understated estimates

Integrated Project Team

ISCM Tool

- Cost
- Schedule
- Risk
- Operability
- CONOPS
- Performance

Knowledge Database Buildup

Total S/V Mass After 10x Reduction in Corresponding Subsystem

Sensitivity Study: Quantifying System Level Effects of Subsystem Changes

Identified two areas for future focused research that will maximize return on research investment

Results

ORS Seven Sisters Mission Cost

Procurement and total mission cost estimate for ORS missions and launch scenarios –

Completed in less than 7 days

Within 5% of other independent estimates

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Summary

Solution to Early Design Challenges of High-Performance Complex Systems

Integrated optimizing tools provide:

Mission/System Requirements

- Operational Assumptions, Conditions and Constraints
- Size, weight, power
- New technology insertion
- Performance
- Schedule

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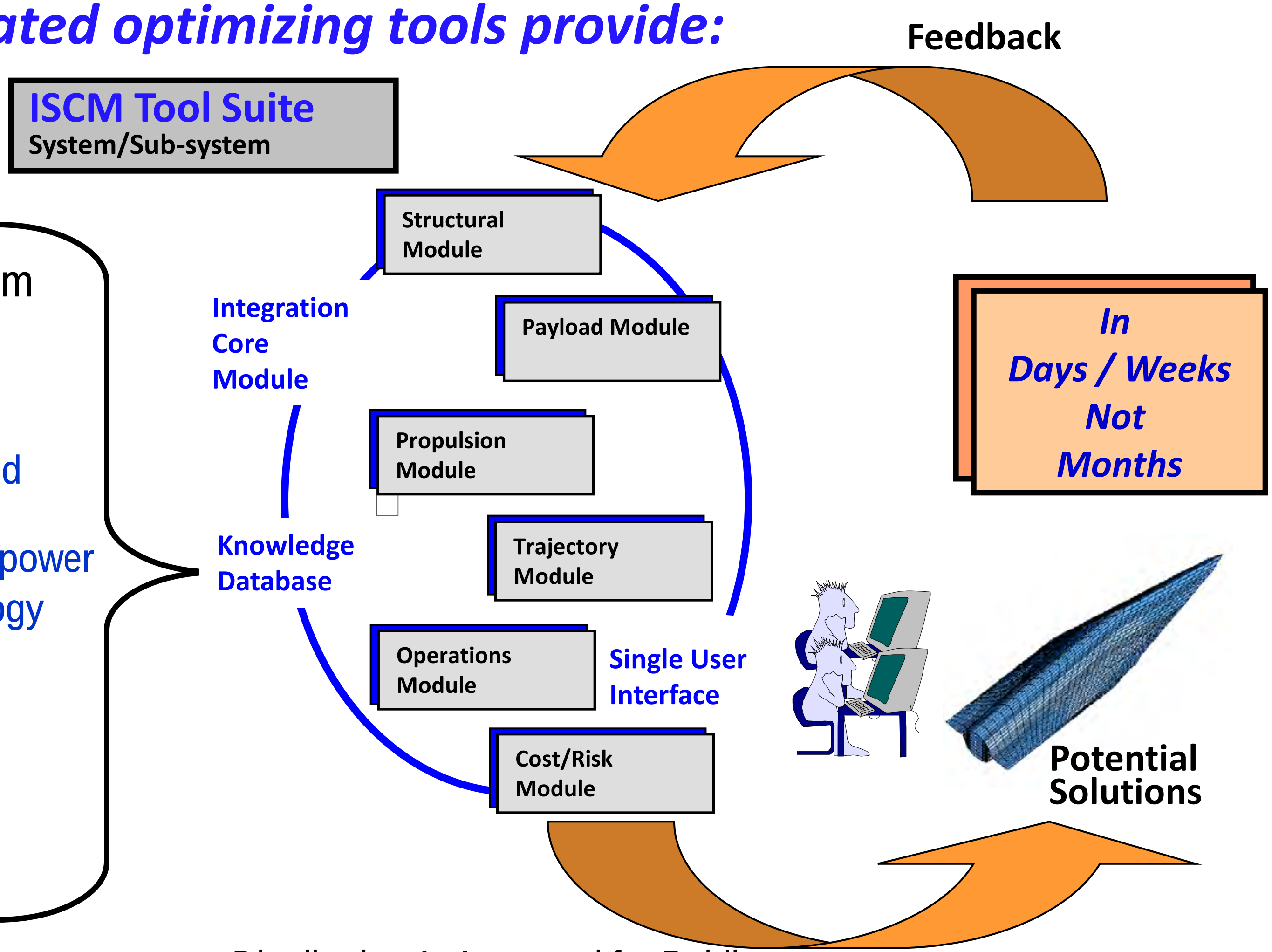

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Future Work

- Improved trajectory optimization for heavily constrained problems
- Enhanced mass estimating relationship
- Increase fidelity of risk assessment
- Improve historical data
- Model additional vehicle classes:
  - Aircraft
  - Rotorcraft
  - Armored vehicles
  - Transport vehicles
  - Communication networks

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Questions?